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LATE PLEISTOCENE CHANNELS IN PORT PHILLIP

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Abstract: Sub-bottom seismic profiling in Port Phillip has outlined a system of late Pleistocene river channels which now lie buried beneath the bay floor muds in the centre of Port Phillip. These channels are continuations of the present day Yarra and Werribee Rivers, which flowed across the bay floor towards Dromana and Capel Sound during lowered sea levels of the last glaciation. They have cut into a firm substrate of middle Pleistocene clays.

The Yarra Channel begins at Princes Pier where it is 1.5 km wide infilled by 6 m of mud and sand. Down the bay it gradually widens and deepens to 3 km width infilled by 12 m of sediment. It then divides into two branches just north of Mordialloc which in turn subdivide into a series of narrow but deeply infilled distributaries opposite Portarlington.

Four channel infilling seismic sequences are recognised. They comprise two densely layered sequences between which is a non-layered sequence. An overlying non-layered mud layer completes the channel sequence and extends out on to the the bay floor. The layered sequences are thought to represent fluvial aggradational deposits whilst the non-layered sequences represent marine deposits. Carbon 14 dates indicate the top mud sequence extends back to 80 000 years BP. The three sequences below remain undated but from sea level curves may include parts of the last glaciation at 18 000 years BP, an interstadial at 80 000 years BP, and an earlier stadial at 90 000 years BP.

INTRODUCTION

Port Phillip on the southern coastline of Victoria is an almost totally landlocked water body of 1167 km^2 and 24 m depth towards the middle. Sand shoals behind the Nepean Peninsula almost close the southern outlet to Bass Strait except for the deep water tidal entrance known as the Rip (Figs 1, 2).

The Port Phillip sunklands are considered part of the Otway Basin, the development of which began as a rift system on the southern margins of Australia in Early Cretaceous times. The sunkland margins are the subparallel Rowsley and Selwyn Fault Systems between which up to 1000 m of Cretaceous and Tertiary sediments have been deposited.

Around the edges of the bay, outcrops of mainly upper Tertiary and Quaternary sediments and volcanics form steep bluffs and offshore reefs, interspersed with long narrow embayments between Recent beach and dune sands.

Port Phillip floor sediments comprise sands around the periphery which grade with depth into muds in the centre. In the south, deeper water muds are juxtaposed against the steep northerly slope of the Nepean Bay Bar sand shoals. Sands and muddy sands cover approximately half the bay floor area.

In 1977, the Marine Geology Section of the Geological Survey commenced a study to correlate the known distribution of the surface sediments of Port Phillip with the aid of a sub-bottom seismic profiler, and to provide additional information on the immediate subsurface geology of Port Phillip and its relationships to the outcrop geology onshore. The results of this survey outlined a system of river channels which now lie buried beneath the bay-floor muds in the centre of Port Phillip (Fig. 2).

Following the sub-bottom seismic survey, targets were selected from the seismic records and were drilled using a vibrocorer to obtain core samples to help identify the main seismic reflectors. The profiling and coring were also designed to assist with interpreting the more detailed coring and sampling programs undertaken by the Ports and Harbours Division around the sand areas of the bay.

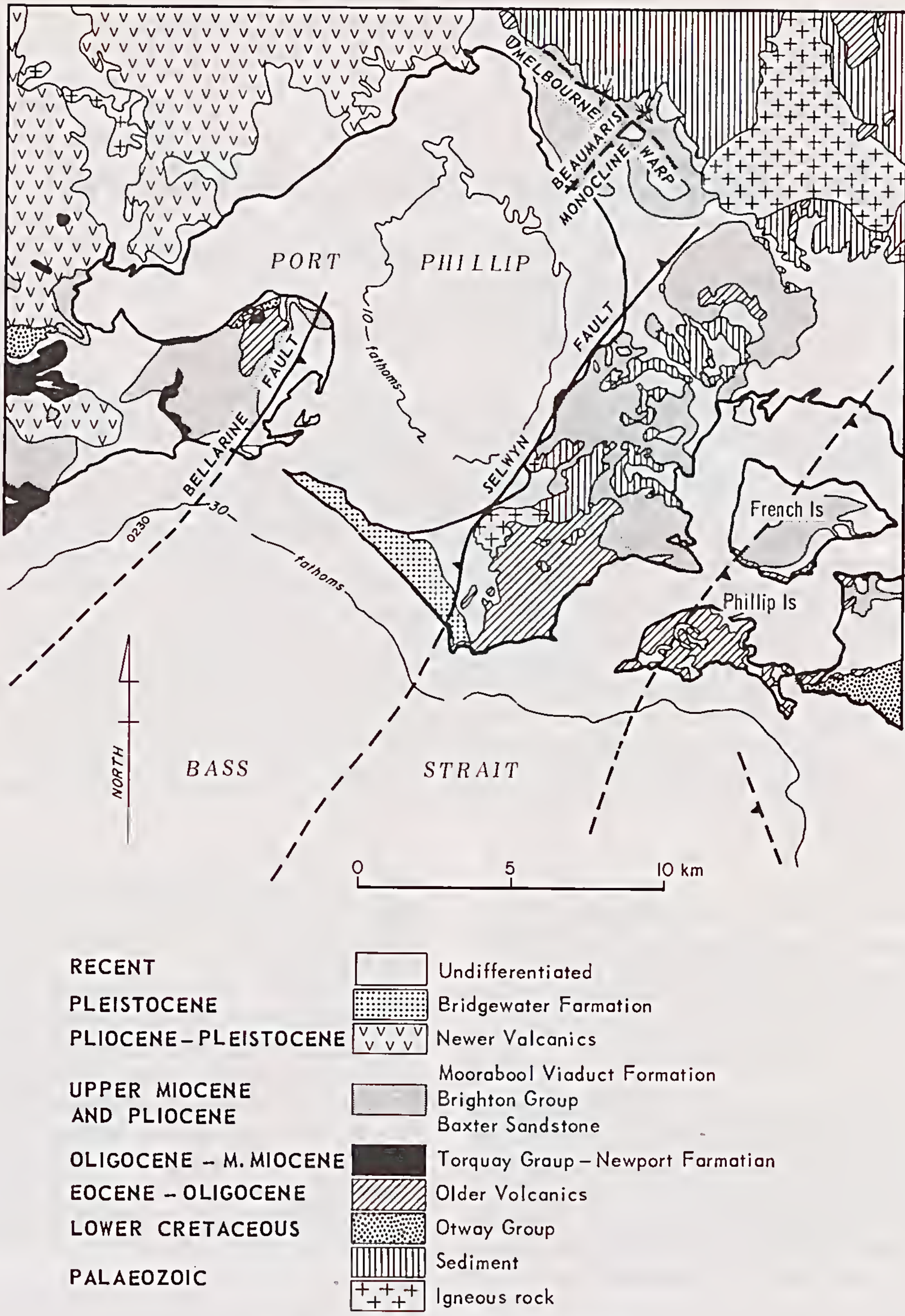

FIG. 1 – General geology of Port Phillip.

A summary of previous work investigating the bottom sediments of Port Phillip (Beasley 1966) and results of the 1957-1963 Port Phillip Survey have been published by the National Museum of Victoria. The first comprehensive seismic survey of Port Phillip was undertaken for ESSO-Australia as part of a study of a submarine pipeline between Mordialloc and Altona. This survey delineated the position of some of the channels described in this paper. Similar seismic surveys, using a boomer in more localised areas of Port Phillip, have since been made by the Geology Department, Melbourne University (Walsh 1978).

Keble (1946) postulated the existence of an earlier Yarra River course from his study of bathymetry in Port Phillip but this work was later regarded as speculative (Bowler 1966). Keble did not conceive the possibility of a buried channel system as outlined by the sub-bottom profiler but, despite this, the two systems are in general agreement as they both coincide with the deepest parts of Port Phillip.

METHODS

The survey work launches supplied by Ports and Harbours mostly contained Decca trisponder navigation equipment for accurate co-ordination to within 1 m or less. Some sextant fixes were made in the northern parts of the bay. Boat speeds during seismic surveying varied between 3 and 5 knots in waters not exceeding 1 m wave height.

The sub-bottom seismic profiler manufactured by Ocean Research Equipment Inc. includes a transducer, transceiver, and a graphic recorder. The transducer hung over the side of the boat about 2.4 m below the surface.

Thirty-six seismic runs, totalling 656 km, were made during 1977 and 1978 (Fig. 3). Most runs occur in NE or SW directions, with an average space between runs of 5 km. Seismic penetration to 50 milliseconds 2-way time (approx. 37.0 m) was obtained under ideal conditions such as in soft muds, with resolution of single beds down to 1 millisecond (approx. 0.7 m). In sandy or consolidated bottom areas penetration was ineffective. As most of the study area comprises soft muds overlying consolidated clays, seismic penetration was adequate to discern most of the younger features.

A signal velocity equal to that of sound in water of 1.5 km/sec was assumed for the unconsolidated sub-bottom sediments and this was confirmed later by coring.

The main seismic events were subsequently reduced using a Hewlett-Packard digitiser and X-Y plotter, and corrected for boat speed and drift (see Fig. 4).

The sediments were cored by a compressor driven vibrocorer which was lowered to the sea bed. The core sample was vibrated out of the core tube into a plastic liner. Maximum core length obtained was 4.2 m. Twenty-eight sites were chosen from the sub-bottom profiling results for coring, and from these about 50 m total of core was obtained.

Results of more detailed coring and sampling by Ports and Harbours on the periphery of the bay were also used for correlation purposes. Additional data were obtained from drilling results for ESSO Australia along the line of the ethane pipeline, and from engineering studies along the Port Melbourne Channel (Holdgate 1977).

Radiocarbon dates were obtained from the Sydney University Radiocarbon Laboratory on five samples submitted, and 15 samples were examined for nannofossils.

RESULTS

The combined drilling and seismic surveys indicated the occurrence of sediments that can be grouped into three distinct stratigraphic units.

Port Phillip — Floor Sediments

1a Peripheral Sands

These occur around the periphery of Port Phillip and on the Nepean Bay Bar. The Nepean Bar sands up to 6 m thick are dominated by tidal currents and display a typical tidal delta morphology. They overlie mid-Quaternary dune limestones from which they derive much of their sand. Elsewhere in the bay the sand forms are dominantly sculptured by wave action and are comprised of a nearshore sand bar zone up to 3 m thick responsive to seasonal variations in wave regime, and an offshore sand zone usually about 1 m thick of dominantly relict material which grades seawards into sandy muds and muds.

The peripheral sands unconformably overlie basement (Tertiary or Quaternary) from which they derive some of their material, and C^{14} dating shows they are mainly Holocene in age. Figure 5 shows the Carbon 14 dates of some samples from the base of the peripheral sands, plotted with various smoothed curves of Holocene sea levels. The dates from shells fall below the curves (they were originally deposited below the contemporary sea level) and the dates from basal carbonaceous material plot close to the Holocene sea level curves.

Remnants of a pre-Holocene marine transgression deposit were found at St. Kilda where iron-stained shells (suggesting sub-aerial weathering) at the base of the peripheral sand were dated at 33 900 ± 2 000 (SUA 994). Since this date is near the limit of practical C^{14} detection and contamination by modern carbon is possible, it is taken as a minimum only. The shells lie at about 5 to 6 m below sea level, and so may be as old as 120 000 years, the last interglacial; later interstadials are not thought to have reached this height (Marshall & Thom 1976).

1b Central Muds

A layer of soft grey mud with some silt, sand and marine shells occupies the central 500 sq km of Port Phillip and grades marginally into the peripheral sands. The muds thicken towards the middle of the bay and overlie a mid-Quaternary basement of consolidated clays, except in the infilled channels where it overlies additional sediments of Late-Pleistocene age.

The muds are designated as Sequence A of the channel infill sequence and north of seismic run 24, are restricted by basement subcrop to within the filled channels. Their thickness is variable where they infill undulations in the basement surface underneath. They average about 4.4 m thick. Outside the infilled channels the muds are usually very shelly at the base. Similar muds occur in the Outer Harbour—Corio Bay area near Geelong.

Nannofossil studies by R. Wilks (pers. comm.) indicate the central muds are of the youngest Quaternary zone and, from their content of molluscan fossils, are thought to be entirely Holocene in age. These sediments are discussed in more detail by Holdgate *et al.* (in press).

2 Consolidated Sediments

The consolidated sediments on which the basement surface is formed are thought to be mainly Tertiary around the edges of Port Phillip (similar to the coastal cliff exposures), and Quaternary in the centre as occurs in the Yarra Delta (Neilson 1976). The relationship between the two is not apparent because sand surface sediments mask their junction but it is thought that Quaternary basement units onlap the Tertiary units in this area. Walsh (1978) reports boomer seismic evidence of post-Tertiary units that predate the channel infilled sequences and onlap the Tertiary.

The basement is not generally penetrated by the seismic frequencies used and, on the profiles, the surface appears as one of undulating erosion. In coring basement, penetration was limited and was generally a stiff clay, mottled and leached in appearance—sometimes with small root fragments. These clays were unfossiliferous but, in the middle of the bay, appear to be similar lithologically to the mid-Pleistocene aged Fishermens Bend Silt (Neilson 1976). On the edges of the eastern side of the bay the cores of basement are lithologically similar to the late-Tertiary sandy clays and sandstones of the cliff exposures.

Mid-Quaternary aeolianites underlie the sands of the Nepean Bay Bar, and eroded Quaternary basalts were also cored on the west side of the bay near Altona.

In relation to the surface marine sediments and the infilled channel sediments, these Quaternary and Tertiary aged consolidated rocks make up the same geomorphic unit, described in this paper as the basement surface. They form the "acoustic basement" on the seismic profiles produced by the ORE acoustic profiling equipment and are referred to as such elsewhere in this report.

3 Infilled Channels

A sediment infilled channel system down the centre of Port Phillip marks the ancestral course of the Yarra River developed during past glacial periods of low sea level. These channels contain three seismic units which are not recognised elsewhere in the bay.

In broad outline (see Fig. 4) the infilled channel system has been traced from offshore in Hobson's Bay at Princes Pier as a single channel 1.5 km wide and with a maximum thickness of 8 milliseconds (5.8 m). Channel floor irregularities and protuberances indicate the valley floor was cut by a number of shifting and meandering stream or river patterns which left isolated ridges in the sub-channel clays. Valley sides on the profiles appear almost vertical in places but when recorrected for vertical exaggeration do not usually exceed more than 10°, and most slopes are probably less than 5°. From Princes Pier the Yarra Channel swings SSW across Hobsons Bay to pass immediately off the end of Gellibrand Pier (Williamstown) south of which it is joined by a second channel from Kororoit Creek. The main channel can then be followed southwards gradually widening and deepening so that on the Sandringham latitude (run 25) it has become 3 km wide and 17 milliseconds (12.4 m) deep. Shortly south of run 25 it splits into two branches of approximately equal width separated by an inter-channel "basement" high as shown in run 24. This splitting also coincides with the spoil ground dumping area, the spoil from which has prevented effective sub-bottom penetration in places, but by run 17 which is past the spoil ground area the between-channel basement high is clearly defined. Sediments in the eastern channel are nearly twice as thick as in the western channel; the latter coincides with the deepest part of the bay floor. This double system continues to the latitude of Carrum at run 19 where both branches bifurcate into a number of narrow but deeply entrenched channel sub-branches with up to 38 milliseconds (27.7 m) of fill. At about this point they are joined by an infilled channel which trends SE across Port Phillip

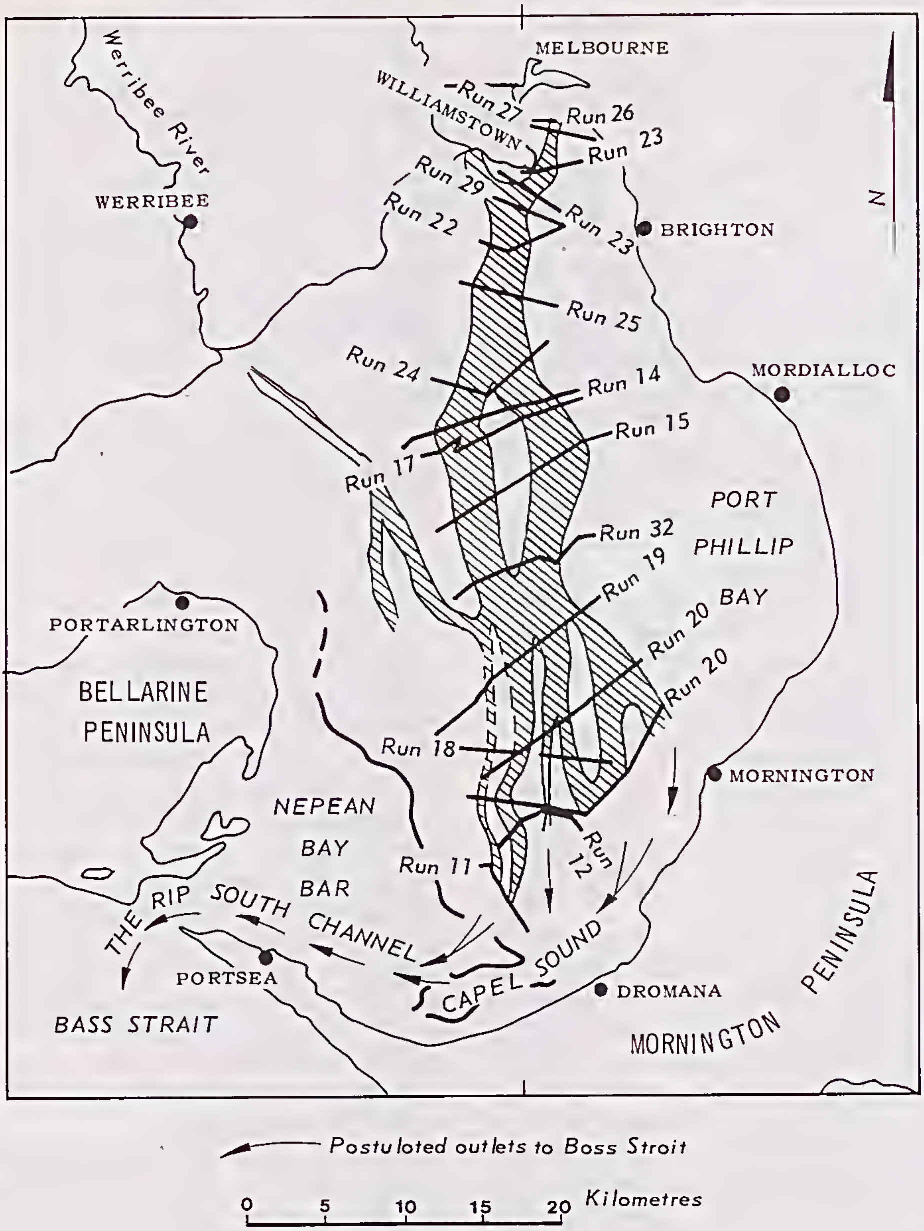

FIG. 2—The late Pleistocene channel system.

from the mouth of the Werribee River. For convenience the western channel branch and its northern extension into Princes Pier will be referred to as the Yarra Channel, and the deeper eastern channel branch and its distributaries to the south are referred to as the Prior Yarra Channel.

As the Prior Yarra distributaries approach the coastline between Mornington and Dromana they are progressively lost on the sub-bottom profile record as they traverse beneath the sandy sediments peripheral to the coastline. The Yarra Channel can be followed the furthest underlying the deepest part of Port Phillip to reach a 27 m sea floor depression immediately north of the Middle Ground sand bank. Further south all the channels are lost beneath the sand banks of the Nepean Bay Bar, but evidence is presented in the discussion to show they all may have joined up in the Capel Sound area and then passed out into Bass Strait via South Channel and the Rip.

The stratigraphy of the channel infilling sequence has been determined mainly from the sub-bottom profiler, as most of the three lower sequences are too deep to be reached by conventional vibrocoring techniques. The correlation of the four main sequences in the centre of the channel down Port Phillip is shown on the cross section Fig. 6—these will be referred to from the top as Sequences A, B, C, and D.

The top sequence (the central muds) is the best understood and is the same as the sea-bottom muds elsewhere in the central part of the bay. It has been cored to maximum 6.05 metres (Esso core No. 3, 3 km south of Williamstown). Acoustically it appears to be a homogeneous unit with few if any strong reflective surfaces. Minor lithological differences noted in some of the cores from this interval may be responsible for the faint banding seen in places on the seismic profiles. It appears to overlie conformably the next sequence down and although it is thicker in the channels it is the only one of the four sequences which occurs outside the main channel areas (Fig. 4).

Below this topmost mud layer and occurring only within the channels is a densely layered sequence exhibiting in places inclined bedding, which thickens and dips down from the channel sides towards the channel bottoms. Beds down to the limits of seismic resolution (0.7 m) are distinguishable and in places drape the sides and across the tops of the mid-channel irregularities. In the Yarra Channel sequence B forms the base of the sequence and at least two cores probably reached this level—Esso core No. 3 drilled towards the edges of the channel 3 kilometres south of Williamstown and contained 2 m of fine quartz sands (sequence B) below 2 m of mud (sequence A); and Australian Dredging core No. 1 off Point Gellibrand contained 0.3 m of grey slightly clayey medium to coarse sand (sequence B) below 2.1 m of brown sandy clayey silt (sequence A).

Where the channel branches into two, south of run 25, the layered strata of sequences B can be followed from the base of the Yarra Channel discontinuously across local hollows in the interchannel basement high to lie across the middle of the infilling sequence in the Prior Yarra Channel, thus forming a contemporaneous marker event across the whole channel system and indicating a previous episode of cut and fill in the Prior Yarra Channel.

It is assumed that the layering within sequence B was produced by a predominant sandy sequence with interbeds of silts and muds. Towards the centre of the Yarra Channel sequence B is about 8 milliseconds (5.8 m) thick and maintains this thickness down the whole channel. On many of the seismic profiles sequence B sediments cause a masking effect below the channel base, which is a similar effect to that produced below a sandy or gravelly sea floor.

Sequence C first appears clearly on Run 24 and after this is confined to the Prior Yarra Channel and its distributaries. This is acoustically transparent and non-layered, and is up to 12 milliseconds (8.7 m) thick. It is seismically identical to the central muds (sequence A). In more southerly runs it appears to include some fine layering. It is not recognised in the Yarra Channel except perhaps on Run 25, and its appearance therefore broadly coincides with the first channel bifurcation.

Sequence C fills in and abutts against the channel sides and drapes over the mid-channel basement irregularities; it has been cut into in turn by the overlying Sequence B. It may originally have extended beyond the channel confines but was removed elsewhere by erosion. The reduced level on top of Sequence C is at no time less than −22 m below present sea level.

Sequence D occurs below sequence C from run 24 south only in the Prior Yarra Channel and like sequence B is strongly laminated and cross-bedded, with beds dipping from the channel sides towards the channel bottoms. On most traverses it is confined to the deeper bases of the channel and its distributaries except on runs 15, 17, and 32 where it has veneered the western channel walls and here is unconformable with sequence C. The seismic record indicates a similar layering of sands, silts, and lesser muds as in sequence B, and on some runs produces masking effects on the profiles indicative of a sandy or gravelly nature. It overlies unconformably what appears to be the same clay basement formation as is present outside the channel areas.

South of Run 24 the base-of-channel slope changes from 1 in 1000 to 1 in 2500, which position also approximates with the splitting of the channels. This suggests that a decrease in slope of the former land surface caused a drop in stream velocities which may be the reason for the change from a single wide braided river valley in the north to a series of narrow meandering valleys in the south. Where all signs of the channels are lost near the Nepean Bay Bar, the channel bases have been cut to a maximum of 66 milliseconds (48 m) below present sea level.

DISCUSSION

1 Age of the Channel Infill Sequences

Lacking confirmatory core data, certain assumptions have been made about the en-

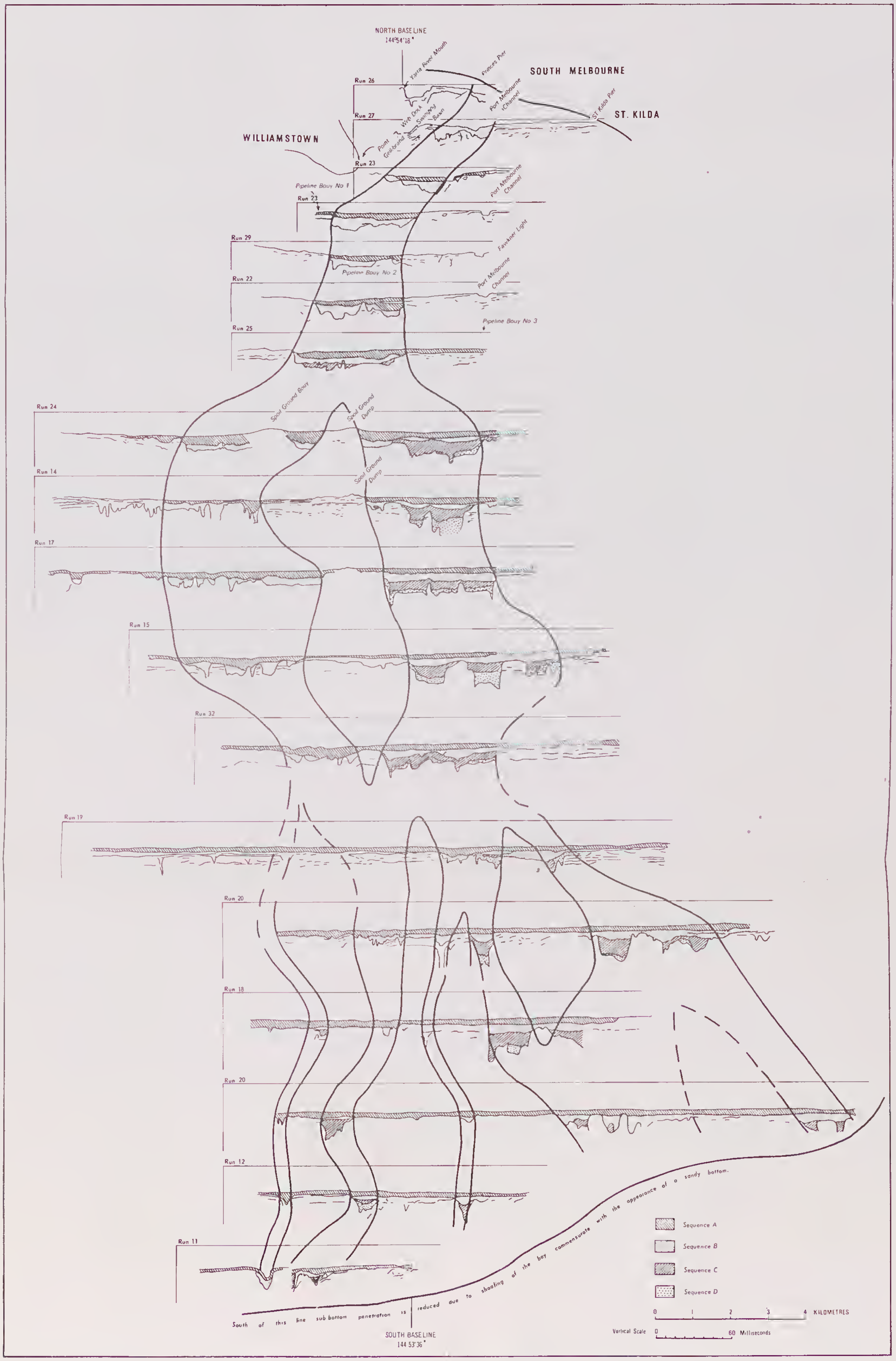

Fig. 4—Stylistic presentation of the late Pleistocene infilled channel systems in Port Phillip.

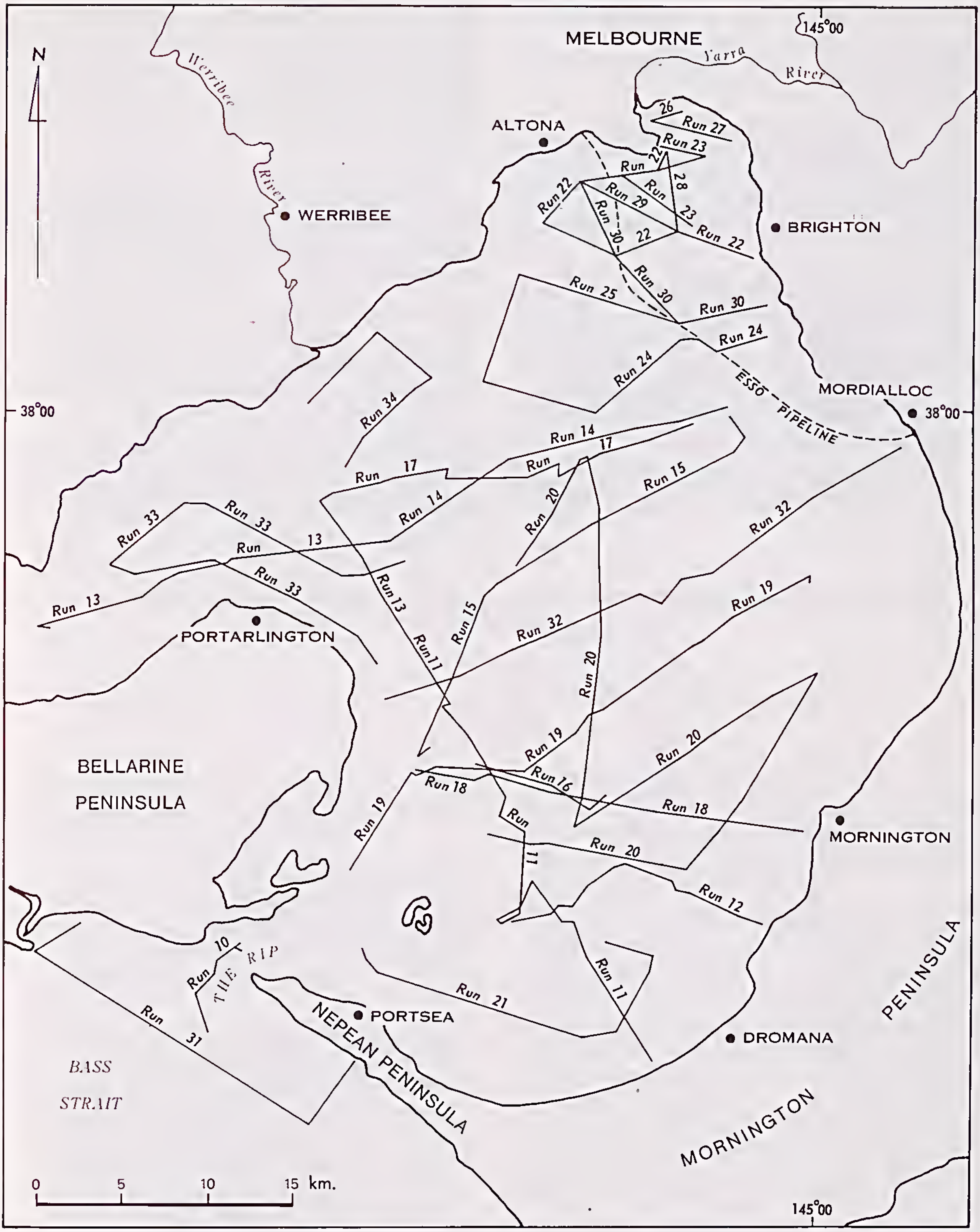

FIG. 3—Locality diagram of sub-bottom runs in Port Phillip.

vironments of deposition of the channel infill sequences based mainly upon their seismic appearances which are more fully detailed in the previous section. These are:

(i) the non-layered Sequence C is similar to Sequence A which is predominantly a marine mud sequence, and therefore both A and C represent depositional periods of marine transgression during rising, and for A, currently stabilised sea levels.

(ii) the layered Sequences B and D from their geomorphic position, stratification and boundary contacts are essentially non-marine fluvial aggradation sandy phases which accompanied or followed soon after the periods of channel cutting, and hence represent periods of regression during glacial stages of falling sea levels.

(iii) from the above it is recognized that the infill sequences of the Yarra Channel represent a single cycle of events beginning with channel cutting, fluvial aggradation, and then later marine infilling. On the other hand the Prior Yarra channels south of Run 25 include this cycle which is superimposed upon an earlier cycle which had followed a similar sequence of events.

If the highest and lowest points of the 4 stratigraphic sequences are plotted as a longitudinal section (Fig. 6) the following events from oldest to youngest, took place to bring about the channel sequence in Port Phillip.

(i) sea level fell to – 48 m or lower – down cutting of rivers into an older and weathered land surface of the Fishermens Bend Silt and Tertiary formations. This downcutting tended to favour the more easterly channel (Prior Yarra) sites.

(ii) aggradation commenced in the channels, depositing *Sequence D* south of Run 25. Either no aggradation occurred north of Run 25 or else the

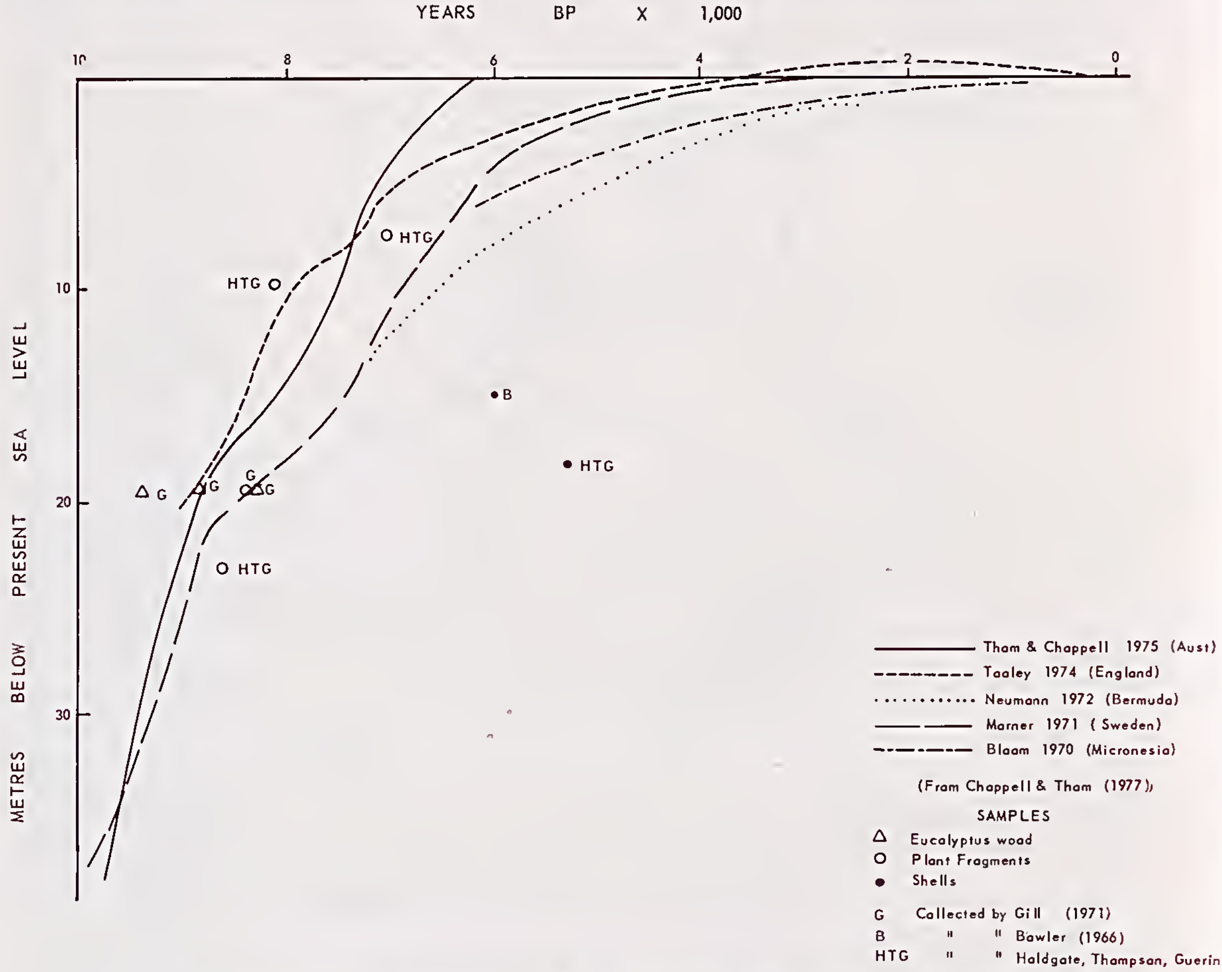

FIG. 5 – Carbon 14 dates in Port Phillip compared with world sea level curves.

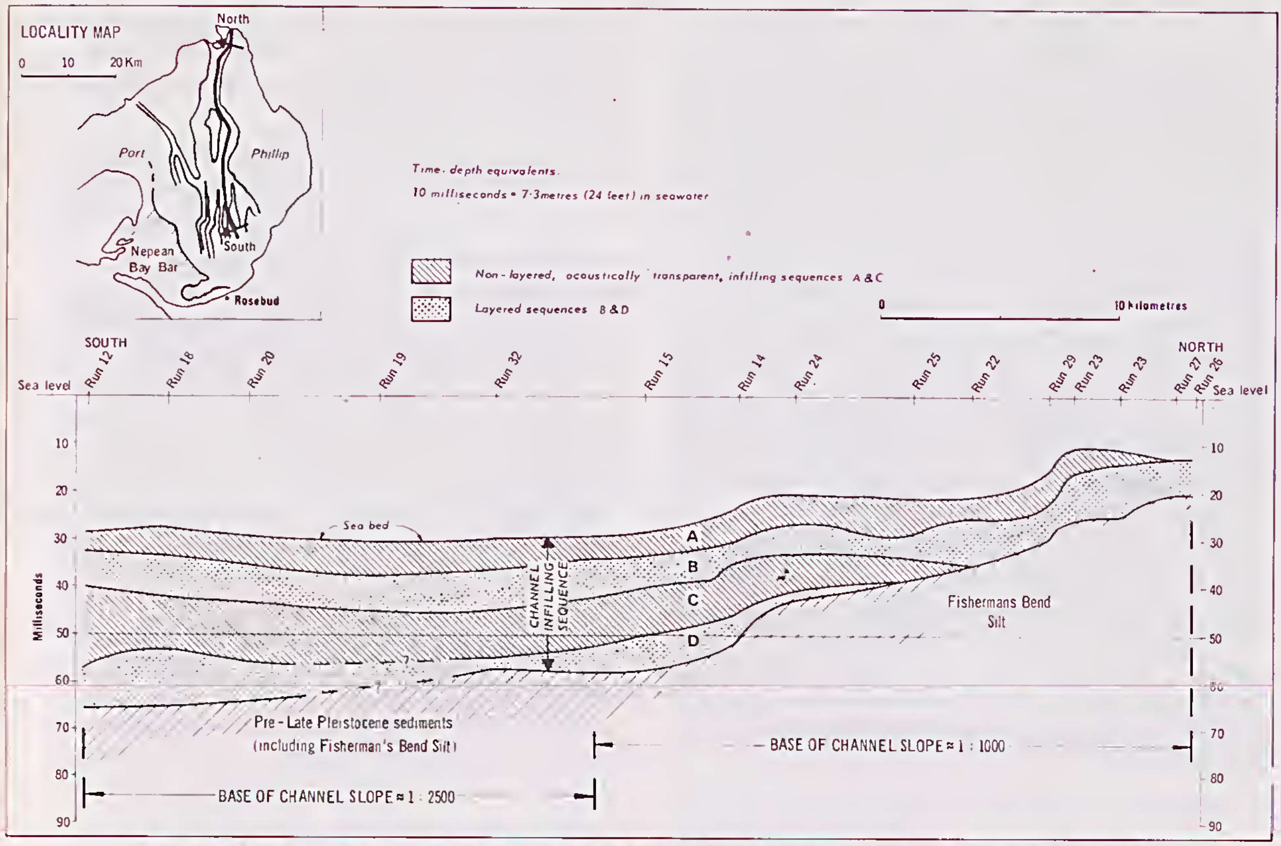

FIG. 6 – Diagrammatic north south section along the late Pleistocene infilled channel system in Port Phillip.

deposited sediments were later removed by younger downcutting events. Meandering of channels occurs south of Run 32.

(iii) sea levels rose to at least – 22 m or higher filling in the channels up to Run 22 with *Sequence C* sediments. These may be only the remnants left by a more widespread marine transgressive deposit later eroded away except within these eastern channel branches.

(iv) sea level fell to – 33 m or lower – downcutting of rivers into the Fishermens Bend Silt land surface occurred mainly west of the earlier channel cutting sites, except possibly north of Run 25 where it followed down the same channel site and removed most of the earlier sequences C and D. Some cutting occurred into sequence C in the earlier eastern channel branches south of Run 25.

(v) aggradation of *Sequence B* occurred along the site of both old and new channels, but favoured the more westerly sites, and also spread across topographically lower positions between the channels.

(vi) sea level rose to that of the present day largely infilling the remaining parts of the channels with *Sequence A* which forms a widespread mud veneer over the central parts of Port Phillip and a sand veneer around the edges.

By tracing back these 6 stages some estimation of ages can be made:

Stage (vi) (rise of sea-level to present day) is partly C^{14} dated by correlation to the peripheral sands and undoubtedly represents the Holocene transgression of the last 10 000 years. From this, Stages (v) and (iv) (fall of sea level to – 33 m, downcutting and then infilling) occurred immediately before and represent the fluvial processes which occurred during the last part of the last glaciation period when sea levels fell sufficiently to leave Port Phillip dry, and therefore probably occurred at around the 10 000 to 20 000 year BP range. Stages (i) to (iii) would therefore have to be older than the sea level minimum of the last glaciation (say 18 000 years BP) but it is not clear whether the marine transgression Stage (iii) represents the last interglacial stage (i.e. 140 000 to 120 000 years

BP), or a younger interstadial transgression such as the −18 m palaeosea level recorded by Chappell (1976) and Chappell & Thom (1978), dated at about 80 000 years BP. Certainly if it was not later removed by erosion, the fact that Sequence C (Stage iii) is not found above −22 m would suggest that sea levels at the time may not have risen as high as at present, whereas the sea levels during the last interglacial stage are generally thought to have exceeded present sea levels (Marshall & Thom 1976). Stages (i) and (ii) (sea level below −48 m, channel cutting then infilling) could therefore represent the earlier part of the last glaciation, say a low sea level stadial before 80 000 years BP but younger than 120 000 years BP instead of being events of the penultimate glaciation of pre-140 000 years BP (Fig. 7).

Either alternative lies well within the absolute maximum age for the channelling events obtained from the 0.81 million year date on the Burnley Basalt in the Yarra Delta which interbeds and underlies the Fishermens Bend Silt (Page 1968)—the latter being considered as basement underlying the central muds and the infilled channel sequences.

2 Channel Pathways to Bass Strait

Evidence for lower sea levels down to −120 m during the last glaciation have been documented on the Australian continental shelves (e.g. Jones 1973) and substantiated in other parts of the world. It could be expected that the channel features formed in Port Phillip at this time would have exited to Bass Strait through the Nepean Bay Bar. Unfortunately the sand shoals of the bar exclude the possibilities of tracing such features with the sub-bottom profiler because of its limited penetration in these sediments, and similarly runs made immediately outside Port Phillip Heads in Bass Strait (Runs 10 and 31) show a similar reflective sandy bottom. Sparker seismic and sampling by the Bureau of Mineral Resources showed sandy sediments form a veneer over much of the continental shelf south from the Nepean Peninsula (Davies & Marshall 1973). No obvious channel-like features were discerned on any of these profiles.

Keble (1946) used the bathymetric contours in Bass Strait to reconstruct a channel course to cut through the Nepean Bay Bar to Bass Strait at around Sorrento. However, this course is not ikely for the following reasons:

(i) the channels all head south towards Capel Sound and Dromana rather than towards Sorrento.

(ii) contouring with more detailed bathymetric soundings by Jennings (1959) indicated little evidence for a channel course in this area of Bass Strait.

(iii) so-called fluvial sediments obtained in bores on the Nepean Peninsula come from a stratigraphic interval now recognised as being Pliocene in age (Holdgate 1976).

(iv) recent bores drilled by the Geological Survey between Rosebud and Sorrento show no evidence of fluvial channels through to Bass Strait. In fact all the bores indicate that the whole Nepean Peninsula has been formed by a series of Pleistocene calcareous dunes (aeolianites) which occur down to −67 m below sea level (not −130 m as reported (Chapman 1928), and often quoted since). These rest upon a Pliocene and older

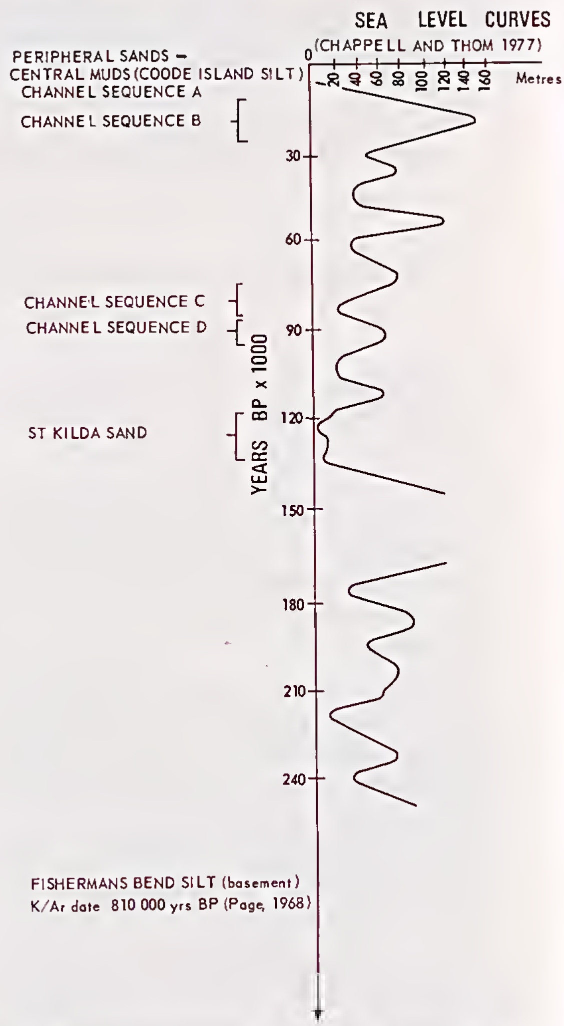

Fig. 7—Stratigraphic units in Port Phillip compared with world sea level curves.